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MUNICIPAL SOLID WASTE: A LOOK AT MAXIMIZING THE DISPOSAL EFFORT

BY

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A REPORT TO THE GRADUATE COMMITTEE OF THE DEPARTMENT OF CIVIL AND COASTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA

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MUNICIPAL SOLID WASTE: A LOOK AT MAXIMIZING THE DISPOSAL EFFORT

ABSTRACT

The "Not in my Backyard" (NIMBY) mindset has reduced the amount of land available for consideration as possible Municipal Solid Waste (MSW) Sanitary Landfill sites. Landfills currently being used are reaching the end of their operating life while regulatory agencies are making the construction of new landfills more expensive and the opening and operating of new landfills more difficult. Some closed landfills have been certified safe for new post-usage considerations, raising the possibility for the dual (though not simultaneous) use of the property. Even with the promising possibility for future use, the amount of land available for sanitary landfills is dwindling while the population climbs and the per capita generation of garbage increases. The key then becomes to make the best use of America's land resource. After a brief history of MSW and a look at how landfills are designed, constructed, and operated, this paper will discuss issues aimed at maximizing the volume of MSW capable of being disposed of within a given landfill. In particular, source reduction, reuse, recycling and composting, waste-to-energy incineration, and landfill equipment and innovations, will be discussed in the context of maximizing a community's landfill space.

INTRODUCTION

The United States proudly leads the world in many categories. However, one category that is more of an embarrassment than an honor is the title of "World's largest" generator of Municipal Solid Waste (MSW). As the largest producer of MSW, America is faced with the monumental task of dealing with this problem. The "old way" of doing business was to dispose of garbage at the dump. The open dump as the name implies was nothing more than the place where garbage was deposited, then left to decompose on the surface. Since open dumpsites are not sanitized at day's end, they become a breeding ground for rodents and insects. Without a proper lining, leachate introduces environmental hazards to the areas. As a general rule, open dumps were also characterized by the lack of rules governing or enforcing what was thrown away. Environmental scientists and legislators have since become involved. Today, "sanitary landfills are well-engineered, well controlled land disposal sites for solid, nonhazardous waste in which delivered wastes are spread and compacted in layers a few feet thick. At least once a day the wastes are covered with a layer of earth and then compacted again" (1, p.1).

Now, many sanitary landfills are approaching maximum capacity, forcing America to rethink this problem. Solutions range from eliminating solid waste to shipping of the solid waste overseas for disposal. Knowing that it is impossible to completely eliminate waste and knowing that other countries are beginning to think twice about accepting this country's waste, Americans are being forced to consider the wide range of solutions that represent internal solutions, i.e. treating the waste locally. This paper begins with a discussion of not just the US history of solid waste, but a more

comprehensive (though greatly abridged) world history. After setting the stage with the historic background, the discussion shifts to the quantity of MSW that is generated. Once the size of the problem has been documented, the discussion centers on the siting, planning, design, construction, permitting, operating, closure, and post closure operations of a sanitary landfill. With a thorough background on MSW and landfill basics, the paper explores ways in which the life of a landfill can be extended. Options range from reusing, recycling, and incineration to the use of geomembranes and better compaction equipment in the landfill operation stage. Finally, the paper will discuss conclusions reached about the various options available today.

HISTORY: A LOOK AT HOW THE WASTE DISPOSAL PROBLEM DEVELOPED

Presently, most garbage in the United States is disposed of within a sanitary landfill. This preferred method represents a solution to a problem arrived at through many renditions of environmental studies, legislative regulations, and cost comparisons. To gain a better grasp of the present practices used in garbage disposal, one must first revisit the past to gain a historical perspective of disposal ideas and methods.

Perhaps as far back as 3000 B.C., citizens of Troy disposed of household garbage by tossing it into the streets where it could be eaten by pigs or partially gathered up by scavengers (2, p.2). Some garbage did not even make it as far as the street, and was instead left lying on the floor. Perhaps as a forerunner to the modern day sanitary landfill, the trash was periodically covered with a layer of soil. In a more sophisticated system, citizens of Mahenjo-Daro, Pakistan made use of trash bins and homes built with rubbish chutes (2, p.2). In 2100 B.C., records indicate that wealthy residents as well as religious leaders in Heracleopolis, Egypt were provided with garbage pick-up and disposal. In this case, disposal represented the dumping of waste into the Nile River. According to archaeologists, the royal bathrooms for the Minoan Palace of Knossos, were built with plumbing to carry away waste from the royal bathrooms. Features included stone sewers fed by terra cotta pipe (3, p.1). Similar sewer systems to those used by royalty in Crete were installed in Jerusalem around 800 B.C. (2, p.2).

As a result of the passage of the first known garbage dump law, Greek citizens were banned from dumping trash directly into the street. Instead, Greece required citizens to collect and transport their own garbage to the town dump around 500 B.C. (4,

p.46). In some cases, this duty was passed off to scavengers who agreed to carry the garbage to the dump in exchange for the opportunity to sift through the refuge. The municipal dumps, by law, were to be established a minimum of one mile outside of the city (5, p.3). Anthropologists today still cherish the discovery of an ancient dump site for so much can be learned there about the community and the way of life.

By 100 B.C., most major Chinese cities had personnel responsible for the collection of municipal garbage (2, p.2). Shortly thereafter, the Roman Empire, stretching from 27 B.C. to 476 A.D., appointed men to shovel street-deposited garbage into a horse-drawn wagon for transport to the dump. Though trash might be deposited at an in-town dump, dead bodies of both animals and humans were disposed of outside of town. The Dark Ages issued in a return to the method used by the citizens of Troy some 3500 years earlier --- disposal of garbage by tossing it into the street (6, p.2).

The easiest disposal method was starting to cause too many problems associated with smell and disease. In 1388, England passed a law forbidding the disposal of garbage in waterways and ditches. Meanwhile, by 1400, the defense of Paris, France was said to be in jeopardy because of an inordinate amount of trash piled high outside the city gates. The city wall became useless as the trash made for an easy ladder to the top to the wall (5, p.3).

In 1657, New York became the first U.S. city to outlaw street disposal of garbage (2, p.3). Scavengers mentioned earlier should probably get the title as "first recycler". That being said, the Rittenhouse Mill in Philadelphia, PA began making paper from recycled fibers in 1690 (5, p.3). Around this time, the Industrial Revolution was beginning in Great Britain and cities were being formed near areas capable of producing

the needed raw materials. In 1842, a British Report linked disease to poor environmental and sanitary conditions (2, p.3). By 1869, England had established a Sanitary Commission, and this was followed up in 1874, with the construction of a machine called "the Destructor", where residents of Nottingham, England were able to incinerate garbage for the first time (5, p.3).

A survey in 1880 revealed that 43 percent of the major cities provided at least a minimal garbage collection operation (6, p.2). In 1885, the United States built its first incinerator on Governor's Island, NY (5, p.3). This allowed for the burning of garbage rather than the more common method of dumping the waste directly on the ground. The first waste reduction plants were used in the U.S. in 1896. These plants were later closed when the compressed organic wastes produced noxious fumes (5, p.3). In 1898, New York used the first recycling equipment, capable of sorting rubbish (5, p.3). Although trash was buried in the U.S. at least as early as 1904, the beginnings of a true sanitary landfill were not introduced until the 1910 timeframe (6, p.2). By 1914, 300 garbage-burning incinerators were in use in the U.S. and Canada (2, p.4). By 1915, 50 percent of the U.S. major cities had minimal garbage collection services (6, p.2). The 1920's saw the use of garbage as a fill in reclaiming swampland (5, p.3). In 1932, scientists in Manchester, England began studying the physical and chemical reactions that occur in the controlled tips or cells within a sanitary landfill (6, p.3). By 1939, all major U.S. cities had incorporated garbage pickup into their city services and by 1948, most landfills were being operated in the "cut and cover" fashion (6, p.2). In its effort to encourage recycling, Olympia, Washington became the first city to pay for the return of aluminum cans in 1954 when perhaps 50 urban communities were still disposing of waste via open

dumping (5, p.3). In the mid-50s, some landfills were beginning to test groundwater near dumpsites because of the realization that the water was being contaminated by the waste. By 1959, most communities had switched to the use of sanitary landfills (6, p.3).

Before 1965, solid waste disposal was not considered a federal problem or issue. Then in 1965, the first federal solid waste management laws were passed. The Solid Waste Disposal Act (PL 89-272), among other things, helped to encourage the buy-back recycling of containers (5, p.4). The Solid Waste Disposal Act set in place a federal research and development effort aimed at developing safe, economical methods for disposing of solid waste. In addition, it encouraged efforts at the local level by providing assistance in the form of technical and financial support. In this early legislation, it is interesting to note that the primary focus was on the problems associated with the above-ground issues (smell, vermin, etc.). The effect of garbage on groundwater was yet to be realized at the federal level although states such as Michigan had realized the problem and had passed protective legislation as early as 1949 (7, p.5). In 1970, the Resource Recovery Act was created as the U.S. celebrated its first Earth Day (2, p.4). The Resource Conservation and Recovery Act (RCRA) was enacted in 1976 and in 1979, the EPA outlawed open dumping (5, p.4).

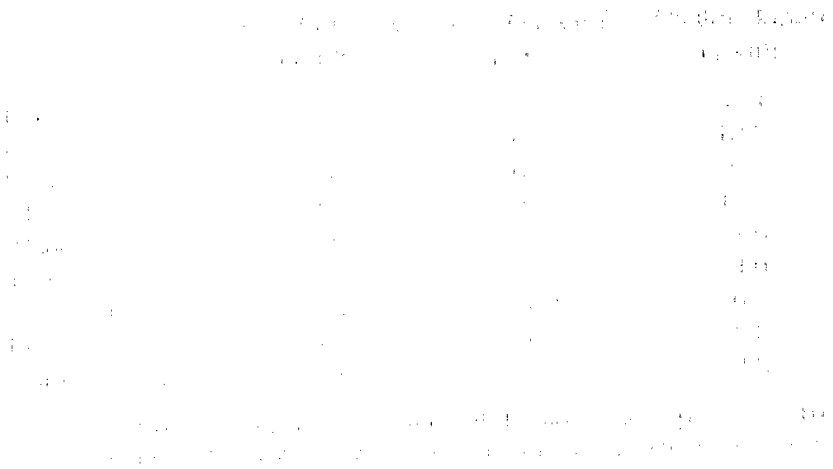
The history of garbage is almost as old as the story of man. Having covered the subject of history, this paper now turns to a discussion on the volume of trash that is generated.

QUANTITIES: A LOOK AT HOW MUCH SOLID WASTE IS GENERATED

Waste is found in both solid and liquid form. A majority of waste, some 90% is found in liquid form. The remaining portion is solid waste of which urban refuse represents the largest portion (8, p.9). Each year, the average American generates 1,613 pounds of garbage (9, p.1). While the U.S. population has grown 34% over the last 40 years, the garbage has grown by a whopping 80% (2, p.4). The disposal mentality of the U.S. culture means that Americans throw away double the amount of Europeans (2, p.4). Urban populations dispose of more waste than their rural counterparts, creating big problems for municipalities. Today's higher wages have resulted in more disposable income which has in turn resulted in more disposable convenience items that generate additional refuge (2, p.5).

"Waste disposal material consists of anything that cannot be further used or recycled economically: thus, its composition varies from community to community, from country to country, as well as from season to season. The density varies from 50 to 400 pcf depending on the amount of metal and debris" (8, p.9). In the last 15 years, the number of active landfills has decreased by some 30%. Meanwhile, the cost to construct a landfill can run up to $400,000 per acre. (4, pp.49-50). With this in mind, it becomes imperative that Americans address this issue. One place to start is in the analysis of the waste stream. Table 1-1 shows the composition of solid waste makeup (8, p.10).

Table 1-1: Average Composition of Solid Waste (Garbage)



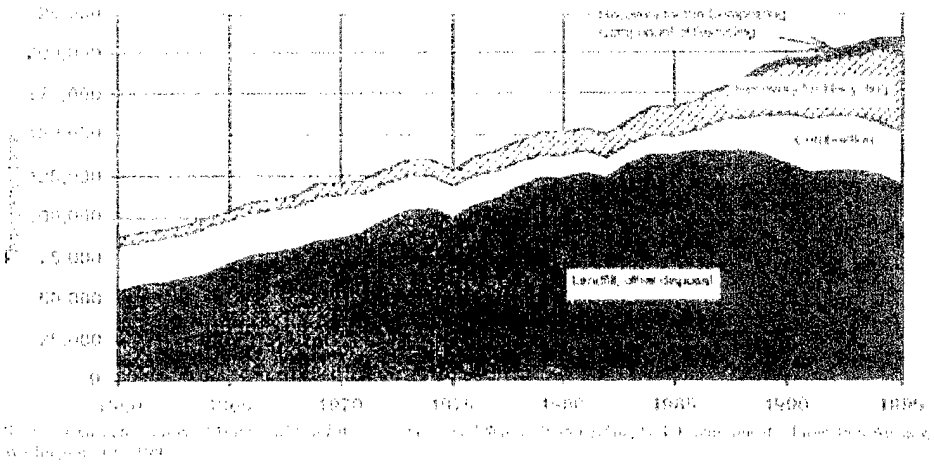
Source: Fang, H.-Y., Introduction to Environmental Geotechnology

A couple of factoids will serve the purpose of showing how widespread and pervasive the waste problem has become (4, p.47):

- The principle cost of food is that of marketing. Second is that of packaging, the part that directly affects the MSW business. "Nearly $1 out of every $12 Americans spend for food and beverage pays for packaging."
- There are more than 46 types of plastic manufactured in the US, most of which are biodegradable and thus if discarded in landfills, with be there for years to come.

Returning to a look at the big picture, Figure 1-1 (4, p.48) shows the current trend of a decreasing landfill disposal volume caused principally by an increase in recycling and composting. The recycling trend is prompted by a lack of landfill space, and is becoming mandatory in communities where the problem is the worst.

Figure 1-1: Municipal Solid Waste Management, 1960 - 1995



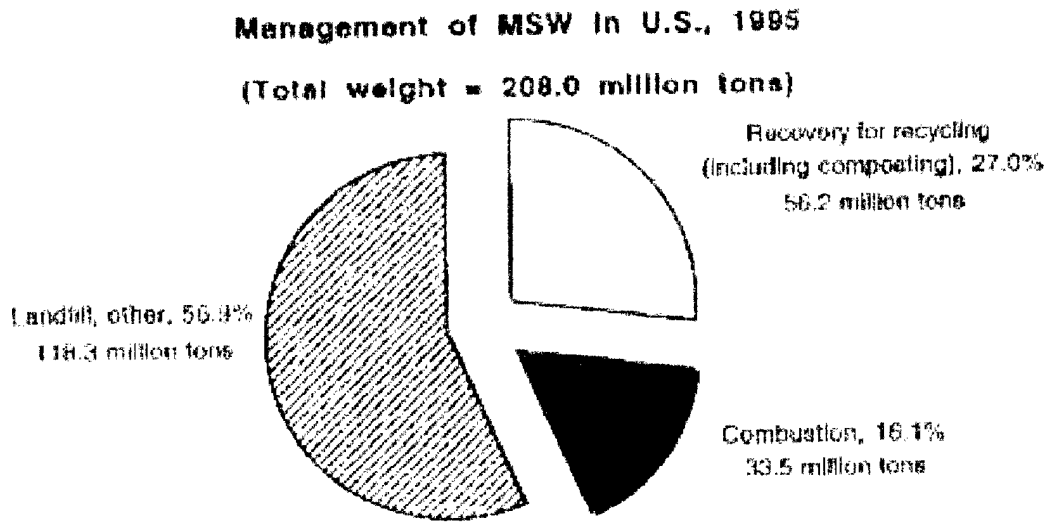
Source: Blair, C., et.al., The Environment: A Revolution in Attitudes

The bottom line is that America generates a lot of trash. When Americans are asked where the trash goes, the typical response would be "to the dump", meaning landfill. The next section takes an in-depth look at landfill design and operation.

LANDFILLS 101: A LOOK AT HOW LANDFILLS ARE SITED, DESIGNED, CONSTRUCTED, OPERATED, AND CLOSED

As shown in Figure 1-2 (4, p.48), a majority of America's MSW ends up in landfills. This section discusses how that 57% of the waste stream is dealt with. The planning, design, construction, operation, closure, and monitoring of a landfill represent not only a significant investment in money and real estate, but also in time.

Figure 1-2: Management of MSW in US, 1995



Source: Characterization of Municipal Solid Waste in the United States: 1996 Update, U.S. Environmental Protection Agency, Washington DC, 1997

Source: Blair, C., et.al., The Environment: A Revolution in Attitudes

The plethora of regulations that must be taken into account extend the time for siting, design, and construction into a 3-10 year time period. The actual operation of the facility, including its monitoring and administration functions, typically lasts 15-30 years. The closure evolution can take 1-2 years and follow-up monitoring and maintenance can last

30 years or longer (10, p.9-11). If remedial action becomes necessary, even more time is needed. The time frame begins with the realization that a community needs an MSW sanitary landfill, followed by calculations designed to estimate the volume requirements needed. The process ends with the on-going requirement for post-closure care. There are 4 basic stages subdivided into a total of 16 individual steps that should be considered. Listed below are the required steps in the life of a landfill (10, p.9-11):

Phase 1

1. Estimating landfill volume requirements.
2. Investigating and selecting potential sites.
3. Determining applicable federal, state, and local requirements.
4. Assessing landfill options for energy and materials recovery.
5. Considering the site's final use.
6. Determining the suitability of sites.

Phase 2

7. Designing the fill area to satisfy plan/permit requirements.
8. Establishing a leachate management plan.
9. Instituting groundwater monitoring.
10. Setting up a gas management plan.
11. Preparing landfill final cover specifications.
12. Obtaining plan and permit approvals.

Phase 3

13. Establishing financial assurance for closure and post-closure care.
14. Operating the landfill.

Phase 4

15. Closing the landfill.
16. Providing post-closure care.

Phase 1 represents the initial feasibility and site selection decisions. The first step, estimating landfill volume requirements is enhanced if municipalities have kept

accurate records of past practices. Without previous documentation, the recommended starting point for calculations is one ton per person per year (6, p.7). Projections for future volume can then be made by taking into account any known changes (population growth, waste type, etc.) expected in the future. These numbers are then revised by taking into account diversionary methods such as recycling, composting, and waste-to-energy alternatives that result in a net reduction of landfill volume. The final volume of MSW can be determined by the composition of the waste stream and the amount of compaction that can be realized. Using a typical refuse-to-soil ratio of 3:1, the amount of soil used for cover is added to the MSW volume to arrive at a total volume.

In investigating and selecting potential sites, one must first take into account the NIMBY mindset of community members. The best plan for the best site can be upended without first considering the community and their possible opposition to landfill siting. A site must be selected that is far enough away to reduce the health and environmental worries of the community, yet close enough to keep hauling distance and costs within reason. When siting a landfill, selection should be based on the following (6, pp.42-43):

1. The risk to public health is minimized.
2. The site minimizes the impact on the environment.
3. The site maximizes the level of service to the facility users.
4. The site minimizes the cost to facility users.

Today's sites are selected for their "hydro-physical and their geographic characteristics. Some of the features that the engineers examine are depth of natural clay liner, depth of bedrock, level of groundwater, aquifer system if any, and watershed" (1, p.1).

From an economic viewpoint, approximately 80% of the costs associated with any comprehensive solid waste management system is that of collection and hauling. Door to door collecting of garbage is labor intensive and thereby expensive. Hauling costs an average of 50 cents per mile per ton (1, p.2). With the volumes of trash being landfilled annually and the long distances sometimes required in traveling to the closest landfill, it is no wonder that these costs represent such a large percentage of the overall solid waste plan. Because of the upfront investment required in both time and money, the site must be large enough to operate for 10 to 30 years. "In selecting a site, some factors to consider include health, safety, accessibility, drainage, soils, proximity to groundwater and surface water, zoning, hauling distance, and adjacent land use" (10, p.9-15). The U.S. Department of Agriculture's Soil Conservation Service (SCS) provides soil maps of the area that can be useful for locating a landfill. The advantage of the maps are that they show areas in which the soil types are best for use as landfills. The disadvantage is that the soil profiles only go to a depth of 5 feet, meaning that additional testing is required once a particular site becomes a serious contender for the landfill site. The soil is an important consideration for 3 primary reasons: it will be used at the landfill as a cover, as a control mechanism for migration of leachate and methane, and as a foundational support for the landfill, the supporting infrastructure, and any future-use considerations (10, p.9-17). Finally, a Geographical Information System (GIS) database is useful in cataloging the various soil types, groundwater levels, terrain, and other categories necessary to aid in the selection of the final landfill site.

During the selection process, all applicable federal, state, and local requirements must be taken into account. At the local level, becoming involved with local boards

allows one to learn the players in the zoning of a new landfill. Also, involvement in the local level includes community awareness and education meetings aimed at comforting the residents. The following requirements may need to be addressed at the state and local level (10, p.9-19):

- a solid waste landfill plan approval
- a conditional-use zoning permit
- a highway department permit (for entrances and increased traffic)
- a construction permit (for landfill site preparation)
- a solid waste facilities permit
- a water discharge/water quality control permit
- an operation permit (for on-going landfill operations)
- a mining permit for excavations
- building permits (to construct on-site buildings)
- a fugitive dust permit
- an air emission permit
- a closure permit

"Regulatory agencies are becoming increasingly critical of landfills, often requiring two and three levels of safety in the approval process for landfill siting" (6, p.18). For instance, approval at the state level normally follows a set procedure: regulatory review, feasibility report, detailed engineering plan, and the final application for operation (10, p.9-28). At the federal level, RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) are the controlling standards. In particular, RCRA Subtitle D mandates state-run solid waste management programs that deal with the approval process discussed above. RCRA regulates location restrictions, design criteria, groundwater monitoring and corrective action, closure and post-closure care, financial assurance criteria, and operating criteria (10, p.9-18). There are many other federal laws that apply to landfills both directly and indirectly. For instance the Safe Drinking Water Act applies to the monitoring of groundwater and the Clean Air Act

applies to gas emissions from the landfill. Of course, the Clean Air Act also applies to incinerator operations.

Since landfills generate gases during their ongoing decomposition of MSW, it is only natural to at least consider the possibilities for using the gas with boilers, with turbines, or as a natural gas supplement. When landfill gas is used for boilers, the gas itself must be at least 20 to 30% methane (10, p.9-19). Similarly, gas for turbines must be either 30% methane or be able to produce 300 Btu's per cubic foot. This provides sufficient power to allow the turbines to drive an electrical power generator. Finally, use of landfill gas is looked at as only a supplement to natural gas because of the difficulty in filtering out other gases. Since only pure methane can be piped via the existing pipeline system, much work is required to upgrade the dirty methane (10,9-20). These energy possibilities will be site specific and should be considered as part of an overall MSW management plan.

An old real estate proverb says that the best time to think about selling a piece of property is before the property is actually purchased. Similarly, the best time to think about post-usage considerations is during the planning stages of the landfill, before any work has even begun on the site. Opposition to a landfill may be reduced when opponents become supportive of the post-usage plans. Money can be saved if the design for post-usage can be accounted for during the design and operation of the landfill. For instance, money can be saved by considering factors such as "cover thickness, slope, cover/waste ratio, degree of compaction, use of additives and cements, selective disposal, and setting aside undisturbed areas as structural pads" (1, p.9-20). Current uses for closed landfills include mostly parks and recreational facilities. The concern about long-

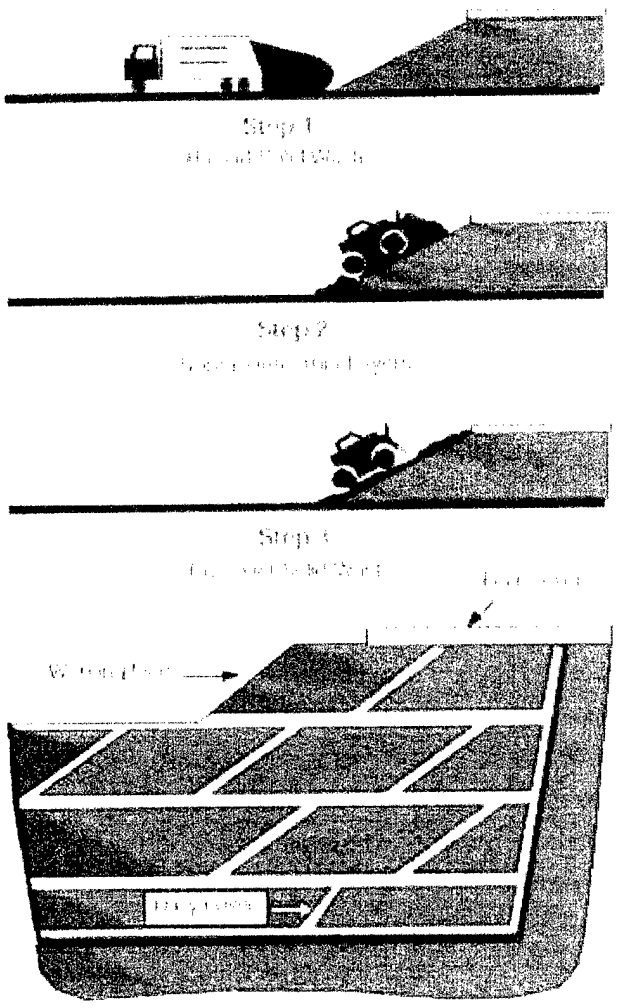
term methane exposure, settlement, environmental and other issues have reduced the number of post-closure plans for residential and larger commercial developments.

The final step in Phase 1 is the shifting of the process from "above ground" collection of data to "below ground" collection. Earlier information gathered should have included suitability of the site based on location, local geography and the buy-in of the community among other things. Now, this step involves an exhaustive effort aimed at gathering subsurface data required before making a final determination on siting of the landfill. As mentioned earlier, soil borings are necessary because SCS documentation shows the soil profile to only 5 feet. Information on the geologic and hydrogeologic make-up of the site must be obtained and analyzed (10, p.9-22). Filling of mined-out quarries is often considered at this point by some to be a win-win solution. Since the quarry is no longer profitable for its natural resources, the land can instead be filled in with MSW. However, this is not as clear-cut as it may seem. When mines are situated over major aquifers, they become potential sources for polluting groundwater. In the United Kingdom for instance, a majority of the abandoned mines were once sources for extraction of chalk, sandstone, and limestone (11, p.278). Because these void sites define the major aquifers, they are off limits as potential landfill sites.

Area landfills represent the most common type of landfill. Figure 1-3 (10, p.9-30) is a cross section, displaying among other things, the working face. A series of individual cells constituting one layer is known as a lift. A single lift ranges from 8-30 feet in height, with larger landfills typically having higher lifts. Faces should be large enough to minimize excessive waiting by vehicles that are offloading MSW, but small enough to minimize nuisances such as birds and blowing paper (6, p.435-437). Desirable

compaction within the cells is 1,000 pounds per cubic yard, but of course this is dependant upon the composition of the MSW (6, p.435).

Figure 1-3:Solid Waste Placement and Compaction



Source: U.S. EPA, Decision Maker's Guide to Solid Waste Management

Besides designing for certain cell and lift sizes, the design must also take into account the liquid, known as leachate, which has been contaminated by the wastestream.

In more detail, "leachate is the liquid that results from rain snow, dew, and natural moisture percolating through waste. The liquids migrating through the waste dissolve salts, pick up organic constituents and leach heavy metals. The organic strength of landfill leachate can be greater than 20 to 100 times the strength of raw sewage, making this 'landfill liquor' a potentially potent polluter of soil and groundwater" (1, p.2). "Leachate, as a chemical substance, takes the constituents of the solid waste mass through which it flow. Thus, there is no 'typical' leachate and the site-specific waste mass must be considered in this regard" (12, p.294).

The moisture contained within the solid waste aids in the decomposition of the landfill. As long as the moisture remains within the confines of the landfill, there are few problems. However, the potential for liquid to exit the landfill, makes the management of leachate a requirement because of the leachate's potential effect on the environment, on groundwater, and on the stability of the landfill. The amount of leachate is influenced by the climate, the topography, the landfill cover, vegetation, and the type of waste (10, p.9-34). The design phase of landfill construction should take into account a calculation for leachate generated, so that proper collection and treatment can be incorporated into the design.

"The purposes of the leachate collection system are to collect leachate for treatment or alternative disposal and to reduce the depths of leachate buildup or level of saturation over the low-permeability liner" (6, p. 253). Clay's low permeability helps to minimize the amount of leachate escaping from the landfill. The leachate that does escape is typically lower in heavy metal concentration because the clay layer acts as a filter.

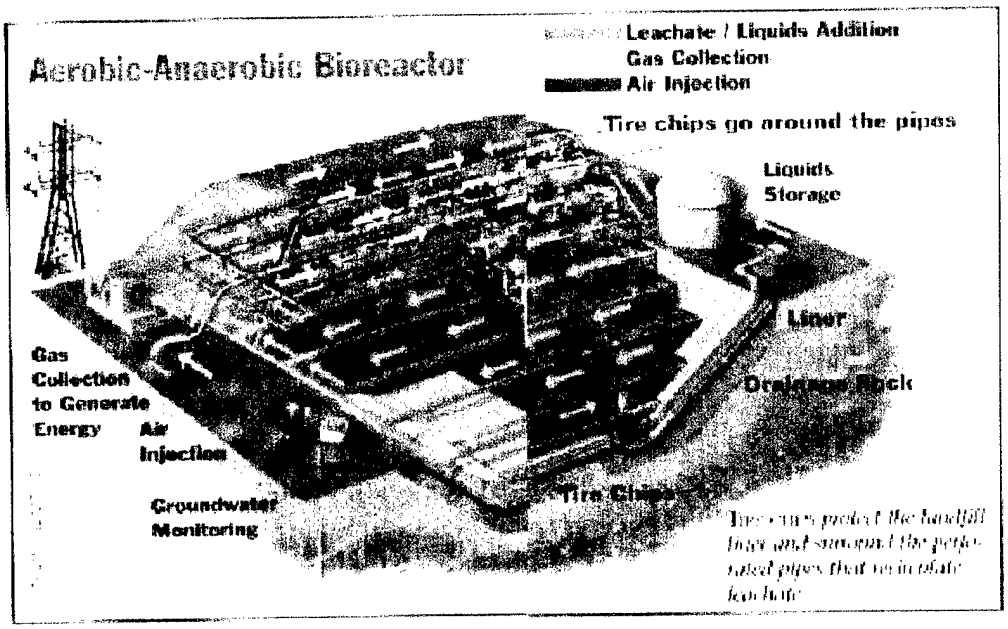
The clay liner is slowly being replaced with flexible membrane liner systems. Because the membrane is so much thinner than would be required for a soil liner, valuable space is reserved for additional MSW. Also membranes may be cheaper than the cost associated with having to transport appropriate soil for liners. Two concerns with synthetic membranes are that the liner's integrity can be punctured or that the leachate could form a chemical reaction that degrades the effectiveness of the liner (10, pp.9/37-38). Because all landfills contain moisture and because all landfills will eventually allow the leakage of rainwater into the site, some landfills are engineered with leachate recirculating devices to speed up the decomposition process (11, p.275). This helps increase the initial settlement and also allows for greater gas collection early on in the process.

Besides leachate recirculation, another leachate strategy is that of on-demand removal. Then there is the method employed in older, abandoned landfills: that of no liquids strategy whatsoever (12, p.296). If leachate is collected, it can be treated on site, or processed at a municipal sewage treatment plant (10, p.9-39).

In trying to make the most of an unfortunate situation, the EPA, in collaboration with Waste Management, Inc., is conducting research at several landfills in Kentucky. Over six million recently recalled tires from Firestone, representing over 20,000 tons are to be shredded into 3 inch squares and used in research projects that will be monitored over the next 5 years. The tires will be used to " cushion landfill liners, embed drainage pipes, and capture gas emissions" (13, p.30). Leachate will be reintroduced into the hybrid aerobic-anaerobic bioreactor landfills as shown in Figure 1-4, after it is collected below the landfill. Storm water will be used to maintain the 35-45% required moisture

level for the operation where the methane produced will be sold to a local utility company. The cushioning provided by the 12" layer of tires will allow compaction after 4 feet of accumulated debris vice 10 feet since the cushioning protects the landfill liner. Second, drainage pipes will be installed into closed landfills as a way of introducing leachate. Finally, tires will be used in a 6 inch biological cap, that uses methanotropic organs to consume the methane (13, p.31).

Figure 1-4: Aerobic-Anaerobic Bioreactor



Source: Forman, S.B., Bioreactor Landfills will use Recalled Tires: Civil Engineering, ASCE

Most research dealing with leachate quantity deals with "generation, collection, removal" and "reinjection for the purposes of accelerated degradation of the waste mass." In that work, "it is shown that the quantity of leachate in a landfill and/or site-specific liquids management program can be critically important both during waste placement operations and, depending, on the geometry of the particular site, quite possible for the landfill's entire service lifetime with respect to the overall stability of waste" (12, p.293). Most incoming MSW arrives at the landfill with a 20% to 40% moisture content. The

flow of leachate is dominated by the percent saturation. For soils, no (or negligible) flow occurs until the voids are approximately 50% saturated. Flow then increases rapidly as the percent saturation increases to about 80%, when the flow reaches its full saturation value (even though some of the voids are not fully saturated). Whether this behavior holds for MSW materials is not known, but it can be assumed that at low saturations, the leachate is discontinuous and held in the voids, whereas maximum flow only occurs at relativiely high saturation values" (12, p.295).

The need for a leachate management plan cannot be overemphasized. One unlined European landfill (designated U-3) failed in 1993, resulting in the death of 27 persons. "Excessive leachate level buildup (estimated to be 5 m), within the old, decomposed waste caused by water infiltrating from adjacent surface water ponds was likely the triggering mechanism of the failure" (14, p.14). This failure of 1,200,000 meters of liquified waste mass resulted in a 1500 meter displacement (12, p.307). Looking back at this failure, plus nine others, it was found that "the triggering mechanisms were all liquid related, i.e., leachate buildup within the waste mass, wet clay beneath the geomembrane, or excessively wet foundation soil" (14, p.1).

The bottom line is that "too little concern has focused on the leachate within the waste mass vis-à-vis its potentially negative impact on stability. With conservative design (e.g., high waste unit weights) and efficient flow and removal within the leachate collection system (e.g., high hydraulic conductivity of the drainage system), leachate within the waste should pose no overriding problems. The possible unwieldy exception is the practice of leachate recirculation which *must* be done with care insofar as both injection location and injection pressures are concerned" (12, p.308).

One recent development in the treatment of rainwater runoff is particularly noteworthy. The North Carolina Clean Water Management Trust Fund has provided a grant for a pilot program in New Hanover County, North Carolina in which wetlands will be used to filter rainwater runoff from a 650-acre landfill. "Plants in the wetlands, for example, cattails, filter waste by absorbing wastewater, while microbes help break down most of the nitrogen, ammonia, and other chemicals in the waste" (15, p.23).

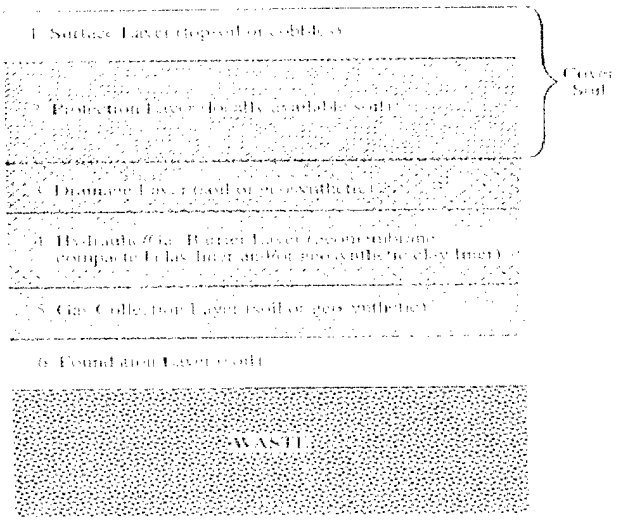
Another part of the construction of landfills involves the installation of monitoring wells. This allows for the monitoring of the groundwater quality, before any MSW is disposed of on-site, during the actual operation of the landfill, and even in the post-closure phase of the operation. "Groundwater monitoring wells are a principle means of characterizing the soil stratigraphy and downward movement of leachate to the groundwater" (6, p.458). This is important because RCRA requires the monitoring, assessment, and if necessary, the corrective action needed to maintain groundwater at least as pure as it was before the landfill began operation.

Landfill gas is composed of carbon dioxide and methane in approximately equal parts plus several other gases in trace amounts (16, p.32). Of particular concern is methane because of its ability to displace oxygen and because of its explosive nature. Depending upon the decomposition phase, the waste biodegradability phase, and the moisture content, landfill gas can be produced up to a theoretical maximum of 300 to 500 liters of gas per kilogram of MSW, with the largest peak seen in the first few years followed by a decline in production over time (6, p.87). "The total quantity of landfill gas to be generated from a unit mass of refuse thus depends on both the organic content of the refuge and on the environmental conditions" (6, p. 86). Methane can be trapped

below ground by clay soils, but can escape into the atmosphere through sandy soils. Because this release into the atmosphere can occur outside the physical boundaries of the landfill property, landfill gas production must be monitored and controlled. Gas can be controlled with an active system or with a passive system. Passive systems that "rely on natural pressure and convection mechanisms to vent the landfill gas to the atmosphere" are less common because of their limited protection and unpredictable nature (10, p.9-46). Active systems make use of a vacuum pump to recover the gas. The quantity and the quality of the gas can be evaluated to determine its marketability. When landfill gas contains 47% methane, it has roughly half of the heating value of natural gas (10, p.9-48). It then may be worthwhile to install the required energy recovery system.

Even in the early design stages, RCRA sets minimum standards for design of the layered cover that will eventually cap the closed landfill. There are 6 typical layers considered in final cover design as shown in Figure 1-5 (16, p.5).

Figure 1-5: Typical Final Cover Design



Source: Koerner, R.M>.,et. al., Final Covers for Solid Waste Landfills and Abandoned Dumps

In designing the surface layer, the following issues need to be considered (16, p.40):

1. What materials will be used to construct the surface layer?
2. How thick will the surface layer be?
3. How will the layer be constructed?
4. For vegetated covers, which plants will be established?
5. Will a geosynthetic erosion layer be employed at the surface?
6. How will the surface layer be maintained?
7. If erosion occurs, will the rates be acceptable?

Similar design questions must be asked with respect to the 5 remaining layers of a final cover. In addition, some thought should be given to the design for support structure including access, site utilities, and storm water run-off.

The final steps before the landfill begins accepting MSW are the attainment of an operation permit and the provision of financial assurance. The operation permit should be just a formality if the public has been kept abreast of the plan from the start and there are no major objections. The financial assurance provision requires the landfill owner to prove that the owner is financially capable of funding the closure of a landfill as well as maintenance for 30 years beyond the planned closure date. Possible sources of financial assurance include "trust funds, surety bonds, letters of credit, insurance, a state/tribal approved mechanism, state/tribal assumption of responsibility, and use of multiple mechanisms (10, p.9-61).

Structural failure of landfills has resulted in death and injury, not to mention the expensive costs of remediation (14, p.34). Therefore, before a landfill opens, all aspects of the process must be checked. Operating the landfill includes more than just receipt and burial of the debris. Inspections are used throughout the entire operation, but are particularly important for screening out items that should not be placed in a particular landfill. Reasons for excluding the waste could range from the fact that the waste is

considered hazardous or to the fact that the waste is considered eligible for a particular salvage or recycling plan. Other items to consider include access control, run-on and run-off control systems, small vehicles and safety, aesthetics, wind-blown paper, bugs, rodents birds, odors, fire, noise, dust, personnel and safety, quality control, record keeping, and community relations (10, pp.9/56-61). Equipment to be used in the landfill is also an important decision and is based upon the volume of MSW and other factors that will be discussed later.

In closing a landfill, the following must be considered (10, p.9-62):

- the degree and rate of post-closure settlement and stresses imposed on soil liner components
- the long-term durability and survivability of cover system
- the long-term waste decomposition and management of landfill leachate and gases
- the environmental performance of the combined bottom liner and final cover system.

Figure 1-6: Procedures for Site Closure

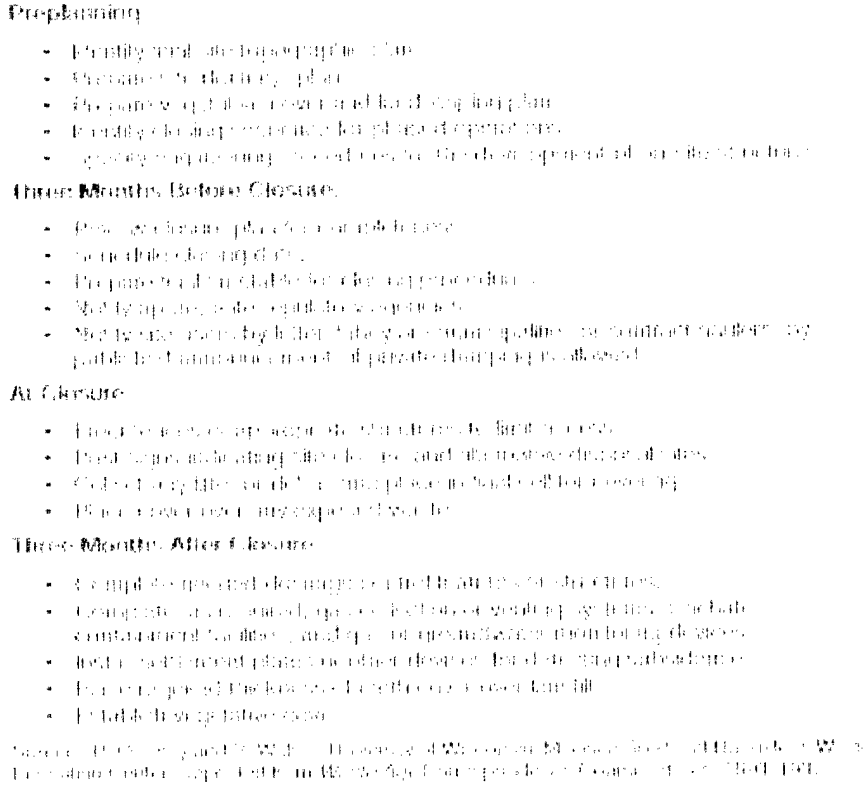


Table 1-6 above lists the procedures associated with the closure of a landfill site (10, p.9-62). Because closure and post-closure operations at a landfill are primarily driven by the need to provide safe human health and a safe environment, continuing care must be given in the following areas (10, pp.9/63-64): general upkeep, road and drainage structure repairs, leachate treatment, groundwater quality monitoring, and landfill gas monitoring. As the landfill life transitions to post-closure care, alternative uses of the site can then be investigated and put in place.

OPTIONS FOR SAVING LANDFILL SPACE

Having covered the basics of sanitary landfill design, construction, permitting, operations, closure, and post-closure, the discussion now focuses on maximization of the space within the landfill. The can be done by implementing a comprehensive solid waste management plan. Strategies can include the following (6, 20-21):

- Source reduction
- Reuse
- Recycling
- Waste-to-Energy Incineration
- Landfilling

Source reduction attempts to implement programs aimed at eliminating the waste before it is even generated. The reuse strategy fosters in consumers the pioneering mindset of finding secondary uses for products that have been previously used. The recycling strategy encourages the reuse of products through reprocessing. This particular strategy is being promoted by special interest environmental groups appealing for American participation as well as legal mandates requiring participation. Recycling can be as simple as that of a composting operation set up in the backyard or as complex as that of a sophisticated refinery. Incineration is the burning of the waste at high temperatures. The left-over ash must still be disposed of within a landfill, but the benefit to incineration lies in the reduction of the waste volume. Incineration can be of even greater value if the process is used to generate energy. Eventually the debris is delivered to the landfill where it is dumped and spread, allowing for covering and compaction to commence. Various pieces of equipment have been specifically designed for compaction duty at the landfill. Using a combination of all options mentioned above can maximize space within a landfill. The remainder of this report will detail these options.

Source Reduction

One way to eliminate the need for additional landfill space is to eliminate the generation of additional waste. This may be easier said than done. However, it is estimated that the current waste stream can be reduced by up to 25% through the following strategies (6, p.20):

- Purchase products with minimal packaging
- Reduce the amount and/or toxicity of the wastes that are now generated.
- Reduce the quantity and cost associated with its handling and environmental impact.
- Reduce waste by designing, manufacturing, and packaging products with minimum toxic content, minimum volume of material and/or a longer useful life.
- Develop and use products with greater durability and repairability.
- Substitute reusable products for disposable single-use products.
- Use fewer resources (e.g., make two-sided photocopies).
- Increase the recycled material content of products.
- Develop rate structures that encourage generators to produce fewer wastes.
- Maintain a compost pile.

One specific example that combines portions of the last two ideas is a program set up in the town of Oliver in British Columbia, Canada where residents are encouraged to separate yard waste. Tipping fees are then cut in half for sorted commercial loads. (17, p.1). This occurrence is quite common throughout the US as well. The individual strategies listed above make it readily apparent that there are and that there should be many overlaps in a comprehensive management plan. Source reduction is just the first step in the overall plan.

Reuse

"Tacoma (Washington) was founded in 1868. In the early years, supplies were scarce, packaging was minimal and products were made to last. People found ways to use, reuse and recycle most everything" (9, p.1). The once popular choice of reusing supplies is now experiencing a comeback. The high cost of landfilling is forcing the return to the reuse strategy. Items can be reused by the same person or by a different person. In the context of "one man's trash is another man's treasure", lies the principle of reuse. By giving clothes, automobiles, furniture, appliances, and books a second owner, additional space is preserved for future landfill use. This can take the form of yard sales where the original owner earns money for his "trash" or second hand stores where articles are actually donated. The use of the word article makes it sound as though these "treasures" are small, but many charitable organizations now take donations of cars, boats, and other valuables. Using the donation of a car as an example, it is noted that 5 functions are served. The original car owner gets a tax deduction. The charity sells the car and earns additional funds for the agency. The money is then available to be given to local citizens in need. The purchaser gets a "new" car. The final beneficiary is the community at large in that landfill space has been conserved. Large corporations are even getting involved in the reuse philosophy. For $29.95, IBM will accept an old computer to use as parts or to refurbish and donate to a charitable cause (18, p.8).

Recycling and Composting

IBM is not the only company with policies aimed at reducing waste. Gateway offers a $50 rebate to customers recycling an old computer (18, p.8). Recycling is the process in which materials and resources are used more than once in either their raw form or through additional processing. About 8% of material that is in a landfill is considered non-recyclable. However, only 12% of MSW is being recycled. Of the MSW, "23 percent is recyclable metal, glass, and plastic; and 41 percent is paper that can be recycled" (19, p.E-7). Various environmental groups have been zealous in their efforts to promote recycling as a policy aimed at saving the environment. Their aim is directed primarily at the demand on the environment caused by America's insatiable demand for user-friendly consumer products. The environmentalists insist that the drain on resources can be somewhat mitigated by the recycling process. This push to do what is earth-friendly only motivates a small percentage of the population. With only a small percentage of the population interested in recycling to save trees, energy, and other resources, one begins to wonder why so many states are suddenly involved in the mandating of recycling. The answer is the skyrocketing cost of landfilling. Legislatures are being forced to implement laws mandating recycling programs. In the process, not only are trees and energy being saved, but so is valuable space within currently operating landfills. California, Florida, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, and Rhode Island are some of the states that have enacted mandatory recycling laws.

Before a community initiates a recycling program, they must first conduct a study to determine the amount and composition of MSW. Care must be taken to include

cyclical patterns caused by seasonal variations in waste disposal. Factors that must be considered in the implementation of a recycling program are "population density, disposal fees, waste generation rates, existing waste handling practices and facilities, available markets for recyclable materials, and public sentiment" (19, p.E-7). Also to be considered are the financial considerations required to implement a new recycling collection and processing program. Collection can include curbside pickup or drop-off centers. As might be expected curbside pickup makes the most sense (financially and practically) in large customer concentration areas and drop-off centers work best (less expensive) in rural settings. The ease of curb-site pick-up (from the resident's perspective) results in higher participation in a recycling program. Of course with curb-side pick-up, there are additional choices to be made, such as requirements to used special disposable bags or reusable plastic containers and how much separation must be done at the source.

If the material to be recycled is separated at the source, it can be delivered to separate locations for final processing. However, there are savings realized in the collection process when the debris can be picked up without having to worry about separating the materials. If enough savings can be realized, it becomes profitable for a community to invest in the construction of a Materials Recovery Facility (MRF). As in all financial decisions, supply and demand of recyclables will dictate the necessity for the added expense of an MRF. By requiring recyclables to be delivered to an MRF, a government can ensure that the flow of recyclables remains constant. Because of the significant capital expenditure required to finance an MRF, the constant flow helps to

protect the owner of the MRF, whether it is the government or a private entrepreneur (19, p.E-8).

Full stream processing is the treatment of not just the mixed recyclable portion of the waste stream, but the full waste stream of MSW. No source separation is required making this option very attractive to participants. "These systems produce a combustible fraction, a compostable fraction, recovered materials, and residuals" (19, p.E-9). Full stream processing is quite common in Europe, but is slow to catch on in the United States, probably because the quality of recycled products is lower when the original products are excessively dirtied by the accompanying garbage. Perhaps future technology will be able to properly sort and clean recyclable products at a full stream processing plant. This would encourage Americans to take a more receptive view of the technology. The current technology is designed to sort materials primarily by size and weight. The process works as follows (19, p.E-9):

- When the materials are first dumped, oversized materials such as white goods and furniture are removed.
- Rotating screens called trammels create two waste fractions: a large-sized materials fraction that includes combustibles and metals, and small-sized materials (e.g., pass through three-inch screen) fraction comprised largely of compostable materials.
- Magnet systems extract ferrous metals from the large materials fraction.
- Air classification can separate the lighter materials fraction from the heavies.
- Light materials including plastic and paper, can be further processed into Refuse-Derived Fuel (RDF).
- The heavy fraction can be mechanically or hand sorted further to recover saleable materials such as corrugated cardboard.
- Disposal of residuals is required.

Current technology allows for the recycling of the following general classes of items: paper, aluminum, steel, plastics, glass, and tires. Of course, the fact that an item can be recycled does not necessarily mean that the item will be recycled. Each

community must evaluate overall costs for implementation before embarking on a recycling program in each of the following areas.

First, paper can be recycled. The four general categories of paper products are corrugated paper, newspapers, mixed papers, and high-grade papers. Each category is considered more valuable when papers from the other categories are not intermixed. The high-grade papers (from office copy machines) are of the most value.

Second, aluminum is in demand in the recycling community. The energy involved in recycling aluminum represents a considerable savings over that necessary to convert raw ore bauxite into virgin aluminum. Aluminum is found in anything from auto parts to beverage cans. The following statistics are of interest regarding aluminum (19, p.E/9-10):

- 100 billion aluminum beverage cans are manufactured annually
- 64% of the cans and 32% of all aluminum products are recycled
- 54% of the material in the cans is recycled material
- 90 days are all that is required to get cans recycled and ready for re-use

Third, steel found in food cans and auto parts can be recycled. Approximately 25% of the steel found in food storage cans is made from recycled products (19, p.E-10).

Fourth, many forms of plastic can be recycled. The recycling effort has resulted in the placement of a special coding system placed on the bottom of most plastic containers. The numbering system is based upon the type of resin that is used in the manufacture of the plastic product. The plastic known as polyethylene terephthalate (PET) is used for items such as soft-drink bottles and then recycled into fill for sleeping bags and winter jackets. The plastic known as high density polyethylene (HDPE) is used

in items such as milk jugs, then recycled into trash cans, flower pots, traffic cones, and food service packaging.

Fifth, glass can be recycled if it is first separated out by color. Flint, clear, and amber glass are all candidates for recycling, but the need to separate cannot be emphasized enough. Mixed color glass and glass mixed with materials such as ceramics are basically worthless. This will change when technology is developed to the point of being able to separate out differences in glass color and composition, but for now, this must be done by the costly and time-consuming hand-sorting process. Like in the case of aluminum, the use of recycled glass results in energy savings. The reason for the savings in glass is that the recycled glass melts at a lower temperature than raw virgin materials used in glassmaking (19, p.E-10).

Finally, tires can and do need to be recycled as part of a waste stream reduction effort. The disposal of 250 million tires per year has resulted in a massive problem. Some tires are being shredded and used as a ground cushion on playgrounds. Other tires are being "shredded to generate tire-derived fuel (TDF), which can be used by electric utilities, pulp and paper mills, and cement kilns" (19, p.E-10). As mentioned earlier, the state of Kentucky has found interesting uses for recalled Firestone tires.

Composting is considered to be another form of recycling. Composting is the process in which yard waste is converted into humus. Yard waste represents 20% by weight of all MSW generated in the US and can represent up to 50% of the MSW waste stream during the peak summer months. This additional volume added to landfills would greatly diminish the lifetime of the landfill. Thus, composting, not only saves valuable space within a landfill, but also provides a useful product for horticulturalists.

Composting involves 3 major steps: "grinding the wastes, conditioning them for moisture and nitrogen content, and subjecting them to aerobic decomposition" (19, p.E-22). Grinding of the larger yard waste items is necessary for the following reasons (19, p.E-22):

1. The particles of waste material must be sized to have a high ratio of surface area to weight: this optimizes bacterial activity and helps to break down the wastes.
2. The material must be homogenized so that added constituents are distributed uniformly throughout its entire mass.
3. The finished product must be homogeneous in texture if it is to be high in quality.

Bacterial activity is encouraged by adding moisture to the mix and by adding nitrogen. The primary source of nitrogen in most large scale composting operations is sewage sludge. This is followed by the aerobic decomposition stage. This reaction generates high temperatures that kill undesirable organisms, minimizing potential health hazards (19, p.E-22). The end result of the compost process is a product for improving soil in gardens and around the house. Because of its usefulness around the house, communities that do not run a compost operation, encourage individuals to compost on their own.

Many states have taken an active role in composting and the promotion of this activity. Since fifteen to twenty percent of Virginia's MSW is composed of yard waste, the Virginia Cooperative Extension has made the following recommendations regarding composting (20, pp.1-3):

Select Appropriate Plants

- Trees and shrubs that produce minimal yard waste
- Trees and shrubs with smaller leaves (easing the composing operation).

Create Easy Maintenance Designs

- Plant ivy to reduce needed pruning and yard mowing.
- Create more decks and patios (but watch for additional run-off)

Leave Materials Where They Fall

- Leave thin layer of leaves on lawn to be mulched and decomposed.

Move Materials to Best Landscape Use

- Use leaves as a garden mulch
- Use leaves to prevent erosion on bare ground
- Use bags of leaves to insulate house frame

Process Materials for Use

- Prune plant trimmings into firewood-sized lengths
- Use smaller trimmings as mulch
- Use old garden plants as winter mulch to prevent erosion

Build a Compost Pile

- Build one as simple or as elaborate as you choose
- Use grass clippings as a nitrogen source
- Use leaves as a carbon and nitrogen source

Give Away Yard Waste

- Find local neighbor or organization interested in using your yard waste

Participate in Municipal Composting

- One way to participate and reduce community costs is to compost in your own backyard, reducing community costs associated with storing the whole municipalities yard waste.

Composting can involve more than just yard trimmings. The city of Long Beach, California collects 16,000 tons of debris annually with its fleet of street sweepers (21, p.25). As mentioned earlier, California is one of the states with mandatory recycling laws. One law mandates a 50% reduction in landfill trash in 2000 (compared to 1990 levels). After removing the non-biodegradable materials, Long Beach was able to

compost about 95% of its street sweeping debris. The actually composting operations are simple, but they do require more treatment than yard waste (21, p.25):

> The material is first sent to a facility where it goes through a screening system that shakes out and separates the dirt and sand from any inorganic materials. Next, all of the cans and bottles are separated out. Then, any other debris that cannot be composted, from shoes to Styrofoam, are pulled out, and the rest of the material, including all of the organics and paper, are composted. Finally, the additional step of removing the contaminants completes the process.

After composting, the former street debris is sold to agricultural interests, saving the community about 25% per year over the costs of landfill disposal (21, p. 25).

Waste-to-Energy Incineration

Incineration is the burning of the organic materials within MSW for the purpose of reducing weight and volume. Incinerators must be built with an easy way to load the MSW and unload the ash. Incinerators must be capable of producing temperatures at every gaseous escape point of 1400 F to burn off potentially toxic fumes. They must also provide grates, agitators, and other features to efficiently burn the MSW. Finally scrubbers are required to filter out any flyash from escaping to the atmosphere. Tangier Island has been in the news recently regarding its incinerator. An agreement has been struck between the Virginia Department of Environmental Quality (DEQ) and the local government of Tangier Island in the Chesapeake Bay that will help to improve the way garbage is disposed of on the island. In this 2-part agreement, fees will be raised to pay for upgrades to the island incinerator to meet current air quality regulations. Secondly, a barge will transport large trash items and incinerator ash off of the island at least once every 60 days. The state is helping to fund these new initiatives (22, p.14). Other communities are also experiencing difficult times in complying with regulations in the landfill and incinerator business.

Though more popular in Europe, some incinerators are built to convert waste (and more particularly waste heat) into energy. An added bonus occurs when waste is converted to energy. Effective waste-to-energy plants have reduced MSW weight by 80% and volume by 90%, while simultaneously producing energy (10, p.9-12). This is done primarily by converting the generated heat into steam by use of a boiler. Some plants spend extra to build a cogeneration plant capable of producing both steam and electricity. Though not as efficient, the overall process may be more economical because

the cogeneration plant does not need to worry about the "non-steam" season. Mass burning, where the full waste stream is dumped into the hopper, is one method of burning MSW. A second process, where the waste is sorted and treated (shredded) to produce RDF, allows the use of coal-fired burners (19, p.E-16).

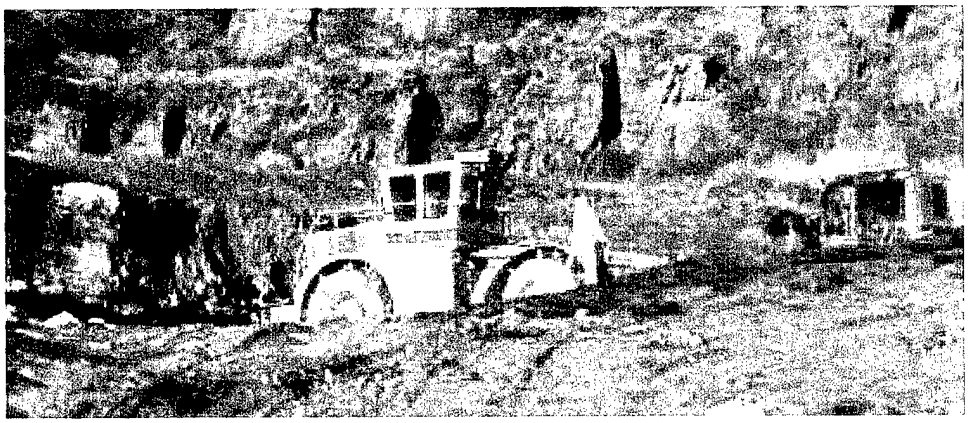
While on the subject of energy, methane must be discussed as well. "Landfill gas is produced by the microbial degradation of the organic components of domestic wastes under anaerobic conditions" (23, p.55). The methane begins forming about 2 years after the individual cells have been closed. One case study showed that enough methane is produced in a landfill to produce electricity for 50,000 homes per year (1, p. 2).

On-site Options

After imposing a moratorium on the construction of new landfills or expansion of old ones, the state of Massachusetts has finally lifted a 5-year ban. "The state's recycling and waste reduction efforts have not sufficiently reduced the amount of solid waste generated in the state to allow the ban on landfill construction to continue" (24, p.11). The immediate focus will be put on the expansion of currently operating facilities because environmental codes and multiple levels of approval will cause lengthier delays for new landfills (24, p.11). Other areas of the country are experiencing a similar squeeze.

When MSW is not reused or recycled, it ends up in a landfill. At this point, it is important to figure out the best way to maximize space within the landfill. Figure 1-7 (17, p.1) (shows a temporary tarp being placed over the daily collection of MSW. By using temporary tarps, valuable landfill space is conserved. Permanent covering such as soil is placed over the MSW only after the cells and lifts have been built up to the proper design height.

Figure 1-7: Temporary Daily Cover



www.oliverbc/ca/public_works/rdos_landfill.htm

A second way to save space within a landfill is through the use of permanent "non-soil" liners. "Landfills in Ohio are required to have a heavy plastic liner or impermeable 'membrane'. The liner covers the natural clay or imported clay liner of a site which is ideally located over a bed rock." (1, p.1)

The EPA requires that all alternative landfill liners meet the same requirements as that of a 24-inch soil layer topped by a .06-inch (1.5 mm) plastic membrane. The alternatives must be tested and proven before being approved. The University of Missouri-Columbia is testing an asphalt liner that has a hydraulic conductivity "100 to 1000 times lower than traditional soil liners" (25, p.36). Since the liner is only 4 to 6 inches thick, the overall savings on landfill space is enormous. A 30-acre landfill using an asphalt liner would be able to handle an additional load of 70,000 cubic yards (50,000 tons) of MSW (25, p.37).

Another type of liner is the geosynthetic clay liner (GCL). The GCL business is growing faster than the 5% growth in the landfill industry. Using Bentonite in a .25 inch layer of the liner is the soil equivalent of 2 to 3 feet of compacted clay. "The Bentonite is combined with a highly impermeable geomembrane to form a composite liner" (26, p.72) "Instead of five to seven dollars per cubic yard for clay (covering about 13 square feet), GCL can cost only about 40 cents per square foot." Since the Bentonite expands up to 15 times its normal size when it comes in contact with liquid, a breach in the liner is in essence, self sealing (26, p.73). Because civil engineers have more training in concrete and steel, geosynthetics is a new and less known subject area to most practicing engineers. The issue is further complicated because there are no current product standards in the industry (26, p.74). Researchers have conducted tests to evaluate site

leachate compatibility with the clay component of GCL (27, p.117). Of course a GCL cannot be approved for use without first undergoing these rigorous tests.

Recently, one expert has argued that the liners are so efficient that the full-fledged monitoring of double-lined landfills is unnecessary in many cases. The argument is not over a single vs. a double lining, but over the excessive cost associated with installing and maintaining an extensive set of monitoring wells to measure a very small amount of potential leakage of leachate (28, p.96). Others counter that this argument is unrealistic because the sample test experiment was not reminiscent of a typical installation process (29, p.7). Of course no matter what liner is selected, tests must be conducted to evaluate the effectiveness of the liner.

The shredding or pulverization of waste results in a reduction of waste volume, by reducing the number of void spaces within garbage. The shredding operation is also useful in prepping some of the garbage prior to incineration. A final shredding use is in preparing mulch in the waste stream reduction area. Whether the debris is shredded and/or incinerated first, or delivered directly to the landfill, the next process is that of burying the garbage and beginning the compaction operations.

Mechanical compaction equipment seeks to provide increased density and stability to the soil. In the case of landfill compaction equipment, the "soil" is composed not only of traditional soil particles, air and water, but also of Municipal Solid Waste (MSW) "particles". Like soil, the physical and chemical composition of the MSW is a major determining factor in the amount of compaction that can be achieved through the use of artificial compaction. Distribution of MSW, initial volume of MSW, and pre-treatment of MSW also play a part in the amount of compaction that can be achieved.

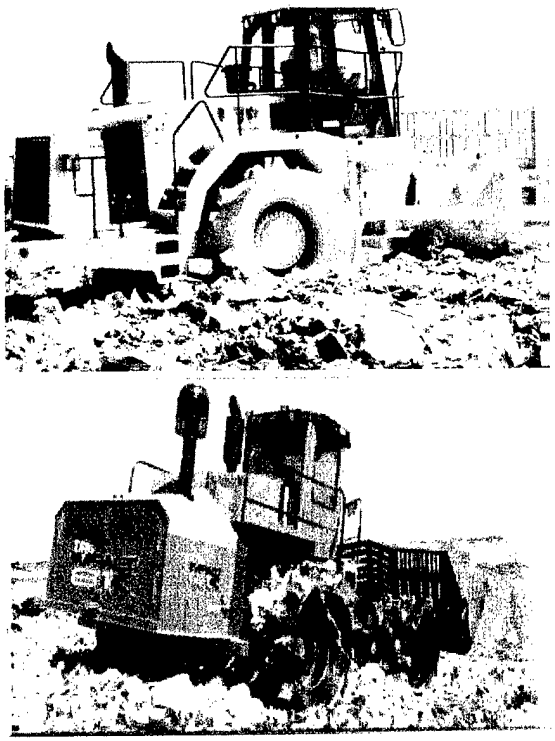
Thus, landfill compaction equipment seeks to stabilize the soil/MSW combination with economic tradeoffs between effort, cost, and availability of landfill space. One way to increase soil stability is to distribute MSW uniformly with heavy items closer to the middle of the landfill property (8, p.533). Best compaction can then be delivered at a 10% slope on the working face (6, p.437).

Landfill compaction can be achieved with many different types of heavy equipment. Small municipalities running their own equipment might be forced to use equipment for multiple purposes. Though this technique will work in landfills, it will not necessarily be the most cost effective as discussed above. In fact, it seldom is. The conditions found in a landfill are much different than those found on a construction site where the base for a building foundation is being prepared or where the base for an expressway is being compacted. Thus several manufacturers have developed specialized compaction equipment for use in landfills. Caterpillar and Al-Jon are the major manufacturers of landfill compaction equipment, with BOMAG and CMI also producing landfill specific equipment. In addition, Caron is perhaps the major player in the manufacture of specialty landfill equipment accessories. Research is currently being conducted on motion planning of multiple pieces of equipment. The use of an automated landfill system (ALS) reduces environmental exposure to workers while at the same time, providing economic savings by compacting with the theoretical minimum number of passes. (30, p.155-156)

A comparison of models Caterpillar 826G (31, p. 1-20) and Al-jon IMPACT 81K (32, p.1-6) (Figure 1-8) will help to point out the similarities common to landfill

compactors as well as differences that are advertised by the manufacturers as reasons to buy a particular brand.

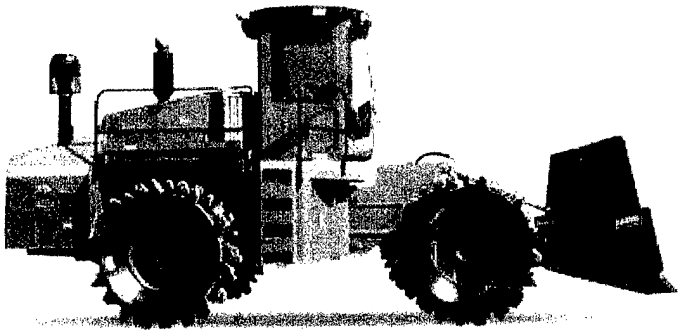
Figure 1-8: Caterpillar 826G (top) and Al-jon 81K (bottom)



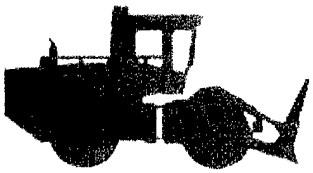
Source: Caterpillar Brochure AEHQ5105-01 (6-97) and Al-jon Brochure Impact 81K

First, the 826G has an operating weight of 76,760 lbs. and the 81K has an operating weight of 81,000 lbs. The added weight on the 81K gives the model a slight advantage when looking at the static weight compaction factor. Second, the 81K is 28 feet long, 14.4 feet wide, and 13 feet high. The 826G has similar dimensions of 27.6 feet in length, 14.8 feet in width, and a height of 12.7 feet. Al-jon really plays up the difference in ground clearance (Figure 1-9) with its "best in industry" clearance of 30 inches. The ground clearance for the 826G is only 20 inches. This factor is important because of the immense lack of uniformity in MSW debris. As the compaction equipment maneuvers over piles of MSW, the underbelly of the equipment is subjected to the potential for wire

Figure 1-9: Landfill Equipment Ground Clearance



Al-jon IMPACT 81K: 30" Ground Clearance - 400 hp - 83,400 lbs.
Wire Wrap Warranty = 5 years or 10,000 hours



Bomag 771: 22 [illegible]
[illegible]
[illegible]

CATERPILLAR 826G 2[illegible]
[illegible]
[illegible]

CMI Trashmaster 3-70C: 20" Ground Clearance
[illegible]
[illegible]

Better by the numbers.

Source: Al-jon IMPACT 81K

wrap and other problems. Of course, the higher clearance gives a higher center of gravity and the potential for rollover is increased, especially on such uneven terrain.

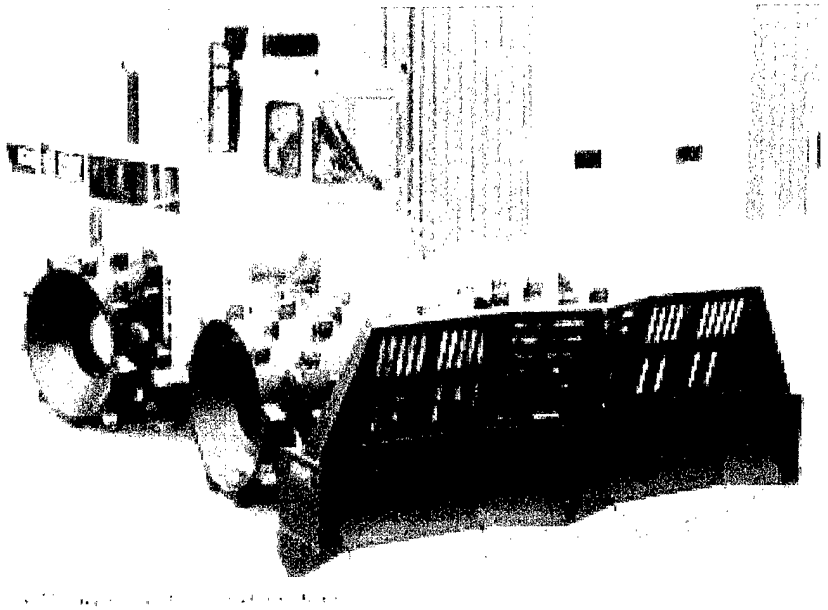
Because the blowing of trash can cause potential problems for the equipment, several trash protection features have been added to each model. The Caterpillar uses a

hydraulically driven sucker fan to cool the radiator with ambient air. The fan can be reversed to blow out accumulated trash on an automated basis or manually from the operator's station. An air inlet screen prevents larger pieces of trash from entering the radiator area. The Caterpillar model also uses power train, hydraulic tank, and steering cylinder guards to shield components from harmful elements of MSW, uses striker bars to help "rake" trash off of the wheels eliminating the chance for MSW to be thrown or carried, and uses a fuel tank located away from debris. The Al-jon model also has a sucker fan installed with an auto-reverse feature. To reduce the amount of dirt and debris, the radiator air-cooling inlet is located immediately behind the cab with two pre-screens providing initial protection. The IMPACT 81K advertises that it has "no live axles to wrap with wire, no universal joints, no mechanical transmission, no torque converter, no differential, no clutch, and no drive shafts" and that "heavy steel plate enclosures protect the articulation joint, wheel drive motors, planetary hubs, engine, hydraulic pumps and all electric lines from contact, wrapping or contamination of debris." (32, p.4). With a sealed undercarriage, no work is required underneath, and presumably, no trash will be detained there either.

The first part of the equipment to make contact with the MSW is the blade. The 826G comes standard with a Caterpillar-made straight blade. Caron Compactor Company manufactures blades that can be fitted on Caterpillar equipment. In particular, Caron makes both a Semi-U Blade and the most popular model, the Double Semi-U (DSU) trashblade (Figure 1-10). Al-jon does not manufacture its own blades and so the Caron DSU blade comes standard on its landfill equipment. The reason that the DSU blade is so popular is its ability to gather the MSW and position it directly in front of the

wheels for the most efficient compaction. In other words, no MSW is pushed out past the edge of the blade and subsequently missed by the compaction wheels during a given pass.

Figure 1-10: Caterpillar 836 with Caron Double Semi-U Blade



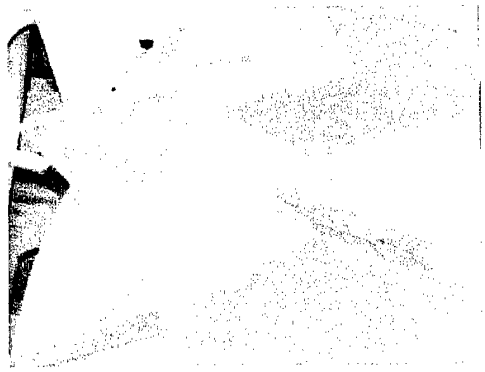
Source: Caron Compactor Company General Product Guide, Revised 1/99

The MSW that is collected in front of the equipment is compacted through the use of specially designed wheels. Like with the blades, Caterpillar manufactures its own wheels. The Caterpillar wheels have Plus-shaped tips (Figure 1-11) that are of the weld-on variety. The tips are spaced far apart to avoid plugging. An added benefit of widely spaced tips is that higher compaction can occur. A second type of wheel, the chopper wheel (Figure1-12), also manufactured by Caterpillar, provides 24 blades per wheel. The staggered blades help to distribute the chopping coverage, and with front wheel blades

Figure 1-11: Caterpillar Plus-shaped Tips

Source: Caterpillar Brochure AEHQ5105-01 (6-97)

Figure 1-12: Caterpillar Chopper Wheels

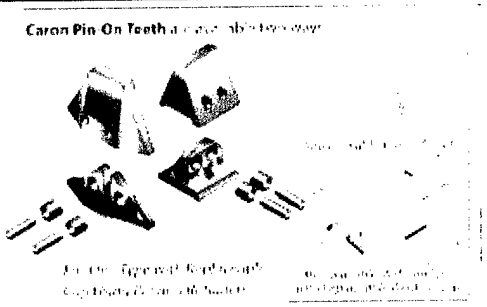


Source: Caterpillar Brochure AEHQ5105-01 (6-97)

angled opposite of the rear wheel blades, improved chopping is realized. Caterpillar manufacturers its Plus-shaped tips and chopper wheels with Abrasion-Resistance Material (ARM) to lengthen the life of each individual tip. Meanwhile, Caron produces tips made of various materials. Tips can be chosen based on the principle environment in which the equipment will be used, expected lifetime of the tip, and the associated cost. The IMPACT 81K comes standard with 48" wide Caron wheels that have pin-on teeth as shown in Figure 1-13 (33, p.1). The pin-on teeth concept allows for the changing out of damaged teeth without the need for welding. This results in less down-time and thus increases the productivity. Caron also manufactures a 40" wide high-density wheel. The smaller wheel puts higher pressure on each given tooth, resulting in greater compaction capacity. Of course, the trade off in this case is the smaller coverage area on a given pass. Besides pin-on teeth, and welded teeth, Caron also offers the option of replacing the entire wheel drum. This option saves time and money when all tips are approaching

the end of their useful lives. Rather than changing out numerous tips, it becomes more practical and more feasible to change out the entire drum.

Figure 1-13: Caron Pin-on Teeth



Source: Caron Compactor Company General Product Guide. Revised 1/99

Landfill compaction equipment is more than just a "souped-up" loader. The landfill is a challenging and unique environment requiring a multitude of features on compaction equipment. Trash protection features, specially shaped blades, and numerous wheel options are but some of the features installed on the machinery to optimize performance and decrease downtime. Understanding the inner workings of the equipment lends itself to maximizing landfill operation efforts. With ever-increasing regulations and ever decreasing availability of land, every aspect of the equipment must be scrutinized. The end result is a highly specialized piece of equipment capable of working in the harshest conditions.

On-site options represent the final alternative for saving valuable space in a landfill. Using tarps as daily covers, making use of geomembranes, properly shredding and pulverizing of waste prior to burial or incineration, and effective use of compaction equipment all lend themselves to maximizing landfill space.

CONCLUSIONS

The history of garbage is a long one. Man has created waste from the earliest of days. The ever-increasing volume of trash, combined with a growing population and fewer landfills presents a challenge that must be overcome. This paper discussed at length, the requirements to design, construct, operate, close, and maintain a landfill. One of the more important considerations concerned the treatment of leachate since it has the potential to cause instability. One landfill failure sited in the paper was reported to have caused 27 deaths. "The task of evaluating the stability of waste falls at various stages in their operation, development and eventually, closure, tests the limits of the geotechnical methods available and poses a number of complex challenges. Little is known about the geotechnical properties of waste materials. Their nature and heterogeneity, and degradation of the organic components of the waste with time are examples of the problems that need to be addressed" (34, p.350). Leachate is also important because of its potential for contaminating groundwater. With a society more attuned to this issue, landfill operators must enhance their communication skills while at the same time being ever vigilant in the monitoring process.

Because our society is better educated about landfills, the automatic assumption is that property values will decrease when a landfill is sited near residential communities. The big picture view is that property value often increases after the landfill has closed. This is because the closed landfill is often unable to support new development beyond that of green space. This keeps the community from being overbuilt and gives a buffer to the residences that had to show patience during the landfill operation phase. Unfortunately this patience may have to last 20 years or so while the landfill is open.

One way to overcome this problem and to provide assurance to local residences is displayed when "privately owned landfills are often willing to negotiate with communities on maintenance of infrastructure and property values to ensure peaceful relationships. These 'good neighbor' or 'host community benefit sharing' programs are case by case approaches to communities working with developers on landfill siting for their mutual benefit." (1, p. 2)

Landfill operation currently ends with the placement of a permanent cap over the final lift. It will be important in the future to keep good records of what is buried in a particular landfill. This is because one potential future use of landfills (given the right incentives, needs, technologies, and costs) is that of mining for "recyclable or reclaimable materials" (1, p.3).

Future investigators might need to look at additional alternatives to that of traditional landfilling. One nontraditional location for siting of a landfill was discussed in the text. The technique of disposing of waste within mined-out quarries was dismissed in England because of the potential for contaminating groundwater. This is not to say that all quarries make bad choices for landfills. There are several landfills in the US that were able to capitalize on this innovative solution, making the best use of what was previously an eyesore with few possibilities. Another unique solution has occurred in Singapore where a "seafill" was constructed between 2 islands in the open ocean. The 63 million cubic meter capacity site was constructed by building a 7 km rock perimeter and all non-incinerable trash is now shipped out via barge (35, p.8).

Even with the use of seafills, mined-out quarries, and other solutions, the available space for disposal is rapidly diminishing. Because there is no single solution to

maximizing the disposal effort, this paper has looked at ways to extend the life of a landfill through a combination of strategies in the comprehensive waste management plan. The place to start is with an all-out reduction of MSW. Several strategies were discussed in this regard. Second, America must return to its pioneering roots by adopting the principles of reuse and recycling. One potential breakthrough in the future will be the development of better sorting and recycling technology to allow for full-scale recycling with minimal or no source separation required. Composting with yard waste, street-cleaning waste, and other debris will also help to free up valuable landfill space. Incineration technology continues to improve, but fights to stay ahead of regulatory concerns mandated in the Clean Air Act. Advances in sorting equipment technology would help to make the waste-to-energy concepts more desirable in the future. In the landfill itself, advances in thin geomembranes have led to increased capacity for MSW disposal. Finally, equipment at the landfill could benefit from motion planning technology in the future.

Because of the individual circumstances of a given municipality, each should be analyzed separately to determine the best procedure. Only after taking an all-encompassing view of MSW as it relates to the community, and after applying the right combination of techniques such as source reduction, reuse, recycling and composting, incineration (including waste-to-energy technology), and landfill equipment and innovation can the disposal effort be truly maximized.

REFERENCES

1. Heimlich, J.E., "Landfill," Ohio State University Fact Sheet: Community Development, Publication No. CDFS-111, pp. 1-3.

2. Blair, C., Quiram, J.F., & Jacobs, N.R. (Eds.), Garbage and Other Pollution, Information Plus, Wylie, TX, 1998.

3. www.theplumber.com/eng.html, The History of Plumbing – Roman and English Legacy, accessed May 19, 2001.

4. Blair, C., Jacobs, N.R., & Quiram, J.F. (Eds.), The Environment: A Revolution in Attitudes, Information Plus, Wylie, TX, 1998.

5. Barbalace, R.C., EnvironmentalChemistry.com: The History of Waste, http://klbproductions.com/yogi/environmental/wastehistory.html, accessed May 19, 2001.

6. McBean, E.A., Rovers, F.A., & Farquhar, G.J., Solid Waste Landfill Engineering and Design, Prentice Hall PTR, Englewood Cliffs, NJ, 1995.

7. Brown, H.S., Cook, B.J., Krueger, R., & Shatkin, J.A., Reassessing the History of U.S. Hazardous Waste Policy – Problem Definition, Expert Knowledge and Agenda-Setting, www.fplc.edu/risk/vol8/summer/brown+.htm, accessed May 19, 2001.

8. Fang, H.-Y., Introduction to Environmental Geotechnology, CRC Press, New York, 1997, pp.1-11.

9. http://www.ci.tacoma.wa.us/garbage/behindthe/history.htm, Solid Waste Utility History, accessed May 19, 2001.

10. U. S. Environmental Protection Agency, Decision Maker's Guide to Solid Waste Management, Volume II, EPA530-R-95-024, Washington D.C., 1995.

11. White, P.R., Franke, M., and Hindle, P., Integrated Solid Waste Management: A Lifecycle Inventory, Blackie Academic and Professional, New York, 1995.

12. Koerner, R.M., and Soong, T.Y., "Leachate in Landfills: The Stability Issues", Geotextiles and Geomembranes, vol 18, no. 5, Oct 2000, p. 293-309.

13. Forman, S.B., "Bioreactor Landfills will use Recalled Tires," Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 3, Reston, VA, March 2001, pp. 30-31.

14. Koerner, R.M, and Soong, T.-Y., "Keynote Paper: Stability Assessment of Ten Large Landfill Failures", ASCE: Advances in Transportation and Geoenvironmental Systems Using Geosynthetics, edited by: J.G. Zornberg and B.R. Christopher, Number 103, Reston VA, Proceedings of Sessions of Geo-Denver 2000, Geotechnical Special Publication NO. 103, pp. 1-38.

15. McGrath, G., "Wetlands Would Filter Landfill Runoff", Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 5, Reston, VA, May 2001, pp. 22-23.

16. Koerner, R.M. & Daniel, D.E., Final Covers for Solid Waste Landfills and Abandoned Dumps, ASCE Press, Reston, VA, 1997.

17. www.oliverbc.ca/public_works/rdos_landfill.htm, Town of Oliver, Public Works, Oliver Landfill, accessed May 19, 2001.

18. Kircher, J.R. (ed.), "What to Do with Old Stuff?", Public Works: Engineering, Construction and Maintenance, Vol. 132, No. 4, 96 pages, Ridgewood, NJ, April 2001, p. 8.

19. Kircher, J.R. (ed.), Public Works: Engineering, Construction and Maintenance, Vol. 131, No. 5, Ridgewood, N.J., April 2000.

20. Relf, D., "Landscaping for Less in the Landfill", Virginia Cooperative Extension: Knowledge of the Common Wealth, Publication No. 426-716, July 1997, pp. 1-3.

21. Kircher, J.R. (ed.), Innovative Sweeping Program: Interview of Jim Kuhl, Public Works: Engineering, Construction and Maintenance, Vol. 132, No. 4, 96 pages, Ridgewood, NJ, April 2001.

22. Geroux, B., "Tangier Island's Pollution Plan is Set", Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 4, Reston, VA, April 2001, p. 14.

23. Bouazza, A. and Vangpaisal, T., "Gas Flux of Partially Saturated Geosynthetic Clay Liners", ASCE: Advances in Transportation and Geoenvironmental Systems Using Geosynthetics, edited by: J.G. Zornberg and B.R. Christopher, Number 103, Reston VA, Proceedings of Sessions of Geo-Denver 2000, Geotechnical Special Publication NO. 103, pp. 54-67.

24. American Society of Civil Engineers, "State Lifts Ban on New Landfill Construction" Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 3, Reston, VA, March 2001, p. 11.

25. American Society of Civil Engineers, "Asphalt Liner Prevents Landfill Leaks," Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 2, Reston, VA, February 2001, pp. 36-37.

26. American Society of Civil Engineers, "New Products, Uses Making News in Geosynthetics," Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 3, Reston, VA, March 2001, pp. 72-77.

27. Simpson, B. "Evaluation of Leachate Compatibility to Clay Soil for Three Geosynthetic Clay Liner Products, ASCE: Advances in Transportation and Geoenvironmental Systems Using Geosynthetics, edited by: J.G. Zornberg and B.R. Christopher, Number 103, Reston VA, Proceedings of Sessions of Geo-Denver 2000, Geotechnical Special Publication NO. 103, pp. 117-128.

28. Koerner, R.M., "Do We Need Monitoring Wells at Double-Lined Landfills", Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 2, Reston, VA, February 2001, p. 96.

29. Peggs, I.D., "Cap Design Recap", Civil Engineering, ASCE, edited by A.E. Powell, Vol. 71, No. 4, Reston, VA, April 2001, p. 7.

30. Tserng, H.P., Ran, B., and Russell, J.S., "Interactive Path Planning for Multi-equipment Landfill Operations", Automation in Construction, vol 10, no. 1, Nov 2000, p. 155-168.

31. Caterpillar, Inc., 826G Landfill Compactor, Brochure Number AEHQ5105-01 (6-97)

32. Al-jon, Inc., IMPACT 81K Landfill Compactor, Al-jon Brochure, 1995.

33. Caron Compactor Company, General Product Guide, Brochure, Revised 1/99.

34. Sadek, S., El-Fadel, M., Manasseh, C. and Abou-Ibrahim, A., "Geotechnical Properties of Decomposed Solid Waste Materials", Proceedings of the International Conference on Solid Waste Technology and Management, 1999, Widener University School of Engineering, Chester, PA, pp. 350- 357.

35. International Construction, "Landfill Site Opens", Volume 40, No.2, March 2001, p. 8.

BIOGRAPHY

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In the Navy, Mr. Tysor has served as Assistant Flag Housing Officer (Public Works Center, Washington DC), and as Assistant Resident Officer in Charge of Contracts (Andrews Air Force Base, MD).

LCDR Tysor has an undergraduate degree in Electrical Engineering from the Georgia Institute of Technology and is a registered Professional Engineer in the Commonwealth of Virginia. He is married to the former Kimberly Hendon and has 2 children, Caleb (3 ½), and Joshua (1 ½).

LCDR Tysor will depart the University of Florida in August 2001 for an assignment with Amphibious Construction Battalion One, Coronado, CA.